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Hybrid Mode of Optical States in Opal-like Plasmonic-Photonic Crystals

A. V. Koryukin[1,2] · **A. A. Akhmadeev**[1,2] · **A. R. Gazizov**[1,2] · **M. Kh. Salakhov**[1,2]

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Abstract

We present an investigation to ascertain the role of the hybrid Tamm-surface plasmonic-photonic mode of optical states in light transmission of opal-like metal-dielectric photonic crystals. The mode of optical states exhibits interesting features in the control of light. Transmission spectra of one-dimensional plasmonic-photonic crystal have a maximum inside photonic bandgap due to excitation of Tamm plasmon in both polarizations. Three-dimensional opal-like plasmonic-photonic crystals have not transmission peak in the bandgap due to unconventional Tamm state. Modeling different versions of plasmonic-photonic crystal, we define the conditions of existence of a polarization-sensitive photonic bandgap transmission peak in the opal-like plasmonic-photonic crystal. Additionally, we also study the condition of efficient excitation of the hybrid plasmonic-photonic mode in such structures.

Keywords Surface plasmon · Tamm plasmon · Plasmon coupling · Plasmon-photonic crystals · Opal-like photonic crystals

Introduction

Tamm plasmon-polaritons (TPP) attract interest due to their potential applications in new types of lasers [1] and high sensitivity sensors [2–4]. TPP are excited in plasmon-photonic crystals (PPC). PPC consist of a photonic crystal and a metal layer providing new ways of control of light due to superposition of their properties [5]. Photonic crystals (PCs) are materials with spatial periodicity of the refractive index [6]. Dimension of PPC coincide with a dimension of corresponded PC (1D, 2D, 3D). Plasmons are collective oscillations in the electric density of a metal [7]. Surface plasmon-polaritons (SPP) are electromagnetic excitations propagating at the interface between a dielectric and a conductor [8]. Thus, the plasmons propagate in a metal and the polaritons propagate in a dielectric as electromagnetic wave. TPP or optical Tamm state are surface waves, one part of which propagates in a photonic crystal instead of a simple dielectric as in the case of conventional plasmon-polaritons. Tamm plasmons have a number of advantages over other plasmonic modes. TPP can be produced by direct optical excitation and may exist in both TE and TM polarizations. TPP have a characteristic peak of transmission in the photonic bandgap of transmission spectra [9, 10]. The photonic bandgap is a frequency window in which the propagation of light through the crystal is difficult [7]. The peak of TPP appears due to electromagnetic field confinement in the Fabry-Perot resonator, where both the photonic crystal (PC) and the metal are mirrors of the resonator [9].

The existence of TPP modes was predicted theoretically in the previous decade [9]. TPP modes correspond to the transmission peak inside the photonic bandgap as experimentally observed on 1D PPC structures in the pioneered work [10]. Tamm plasmon exciton-polariton modes were proposed to be used in exciton-polariton integrated circuits [11]. Hybrid modes of Tamm and surface plasmon were studied in various systems such as 1D PPC [12–15], cavity-assisted quantum dots [16], Bragg mirrors [17], resonator-based array in sensors [18], photonic quasi-periodic configurations [19], and PPC containing liquid crystal microcavity layer [20]. TPP was investigated in experiments including second and third harmonic generation [21, 22], fluorescence emission [23], refractometry [24], and reduced light absorption by intracavity metallic layers in a Tamm plasmon-based microcavity [25].

2D PPC attract interest due to their potential applications to increasing propagation distances of surface plasmons [5]. In various studies, 2D PPC were synthesized, for instance, as self-assembled structures [26], hexagonally arranged circular

✉ A. V. Koryukin
akoryukin@gmail.com

1 Institute of Physics, Kazan Federal University, Kremlyovskaya 16a, Kazan, Russia 420008

2 Institute of Applied Research, Tatarstan Academy of Sciences, Bauman 20, Kazan, Russia 420111

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